

SILTATION REGIME OF ARTIFICIAL RESERVOIRS IN THE REPUBLIC OF MACEDONIA

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Abstract: The artificial reservoirs are multiuse objects and they are very significant for growth of both water development and agriculture. With explicitly harmful water activity (pluvial and fluvial erosion), there are about $3,0 \times 10^6 \text{ m}^3$ deposited sediments, in the existing reservoirs in the state. So, every year, their capacity decreases and the reservoirs will become unseals cataract.

The subject of this research is few reservoirs in Macedonia.

This work presents a recapitulation of long term measuring of the reservoir siltation. There are several micro-reservoirs already silted to the top, thus they are used now as an agricultural land. The bigger reservoirs meet the same dramatic situation, particularly as a result of lack of undertaking anti-erosion actions in their catchments.

The aim of the research is that through studying and analysis of natural conditions and previously measurement to define regime of siltation into the reservoirs.

Keywords: *soil erosion, intensity of the erosion, siltation regime, artificial reservoir, intensive rainfalls.*

1. Background

Water as a natural resource is the basic and irreplaceable component for existing, survival and development of all of the live existence on the planet Earth. The permanent increases of the population, the need of water for different purposes, as well as the negative effects of the human actions, are increasing permanently. These two contradictor components are contributing for permanent decrease of the quantity of qualitative water resources.

The water reservoirs, especial the artificial ones are of an invaluable significance for the development and the prosperity of the civilizations

The big importance of the reservoirs for living and development of the Republic of Macedonia, the needs for maximum exploitation of the water potential and more pointed community and individual interests for rational usage of water, leads to the need of their permanent observation and studying. The intensive filling of the reservoirs with erosion sediments is the subject of these researches. As a consequence of the erosion processes at the basin areas and the porous activities at the riverbed of the water currents at the permanent reservoirs at Republic of Macedonia in average about $3,0 \times 10^6 \text{ m}^3$ of erosion sediments are being deposited.

Characteristic about the Republic of Macedonia reservoirs, especially the ones with a high length of the water mirror is that the biggest part from the alluvium is deposited at the live storage of the reservoirs.

The occurrence and process of the soil erosion in different kinds, forms, types and intensity is presented on the whole planet and is in direct connection with the evolution and civilization development as well as the everyday human activities for survival and prosperity. As an occurrence and process it is a consequence of the effects of the nature and zooantropogenyc factors, were according to the specifictories domination and the intensity of these factors, it is in condition to cause some big negative effects at the economic and even culture development of one community.

The erosion processes in the catchment areas and the erosion activity in the catchment areas, endarged and destroy large areas, productive lands, infrastructural objects and systems, inhabited places act. The activities against drought and flood, in the same time

are activities to combat erosion too. According to the spread ness and the intensity of the erosion processes and the permanent activity at the already existing hydrography net in RMacedonia are present some more significant areas with erosion processes of different kind, shape, type and intensity. The specifications of the kinetics, orographic, geological-penological, vegetation, hydrographers, hydrological and other nature factors, in action with the strong effect of the zooantropogen, factors, have determined the occurrence of a lot of very intensive erosion processes.

The already existing reservoirs are of enormous contribution for improvement and regulation of the water regime and deposit, but as a State we are still very far from the condition of complete regulation and control of the hydrological potential The filling of the reservoirs with erosion material is a nature process that is depending of the erosion potential in the catchment area, in smaller or bigger point it is determination the age of profitability of their usage. The taking over and the implementation of the antierosion measurements and activities, and according to the previous complex diagnostician and improvement of the potential of the erosion processes in the catchment area areas of the accumulation is a basic term for their rational and rentable and long-term usage.

2. Location and subjects of studying

At the moment, there 19 big dam, 2 are in phase of building, and over 120 small dams (Figure 1).



Fig. 1 – Big dams and reservoirs in the Republic of Macedonia – current condition

Table 1 – Parameters of existing and big dams under construction

No	Name	Year	Type	H	Lc	TRS	URS	Purpose
				(m)	(m)	10 ⁶ m ³	10 ⁶ m ³	
1	Glaznja	1972	A	74.0	344	23.6	22.20	I, WS, E
2	lipkovo	1958	A	32.2	133	1.2	1.1	I, WS, E
3	Mavrovica	1982	EF	24.0	360	2.8	2.5	WS, E
4	Kalimanci	1969	RF	85.0	232	127.0	120.0	I, E
5	Gradce	1959	A	29.0	150	1.8	1.8	I, WS
6	Ratevska	1972	A	49.0	194	10.5	9.7	I, WS
7	Paljurci	1977	EF	21.1	386	2.9	2.8	I, R
8	Matka	1938	A	29.5	64	3.7	1.8	E
9	Otovica	1968	A	27.0	73	8.0	3.8	I
10	Prilep	1966	MA	36.0	409	6.0	4.5	I, WS
11	Tikves	1968	RF	104.0	338	475.0	360.0	I, E
12	Strezevo	1982	EF	76.0	632	119.3	109.0	I, WS, E
13	Suvodol	1982	EF	33.9	941	7.9	3.9	R, WS
14	Turija	1972	RF	77.5	417	50.3	47.8	I, WS, E
15	Vodoca	1965	RF	44.0	185	27.0	26.0	I, WS
16	Mantovo	1975	RF	37.5	138	47.5	40.0	I, WS
17	Globocica	1965	RF	82.0	196	58.0	13.2	E
18	Spilje	1969	RF	101.0	330	520.0	212.0	E, I
19	Mavrovo	1952	EF	54.0	210	357.0	274.0	E, I
	Lisice	-----	RF	66.0		23.0		WS, I, R
	Kozjak	-----	RF	126.1	306	550.0	360.0	E, R, I, WS

Legend:

A – arch; MA – malty arch; EF – earth fill; RF – rock fill

H – height above terrain

Lc – crest length

TRS – total reservoir storage;

URS – useful reservoir storage

I – irrigation; WS – water supply; E – energy; R - flood retention

3. Study methodology

The monitoring of the filling of the reservoirs with erosion deponents in RMacedonia dates from the beginning of the building of the bigger reservoirs (Kalimanci⁴ and Tikves¹¹) i.e. from the year 1968.

The working methodology (investigations) was realized according to the following actions and principles:

1. Collection and study all previous data about the reservoirs, erosion, data from measuring;
2. Erosion map analyse and estimation erosion coefficient (Z) for elected catchment areas (by Gavrilovic methodology)
3. Estimation quantity of produced and transported erosion sediment (by Gavrilovic methodology);
4. Cross analyse

The preciseness of the realised measurements, calculations and analyses of the deposited sediment in the RM reservoirs, depended of the choice of the methodologies, qualitative and technologies and the equipment, qualitative of the basis, the accommodation of the equipment to the morphological and the other characteristics of accumulation act.

For some determined reservoirs in R Macedonia the mean annual quantities of the deposited sediment are determinate with the following methodologies:

- on the base of water turbidity i.e. the secondary incomes of the suspended sediment

- direct measuring by echo sounder
- analytical qualitative – quantitated methodology (analytical) by S. Gavrilovic;

Estimation of deposited on the base of the secondary incomes of the suspended sediment measured on the hydrometric profiles is not real. Due to any preview researches, great part of deposited sediment is bed load, so relation between suspended sediment and bed load couldn't be estimated real. So this method is out of use.

The best way to determinate quantity of the deposited and expected sediment at the reservoirs is thru direct measurements of the deposited sediment but for pure country as Macedonia it is so expensive. Although Act of Water of RM predict permanent annual measuring of deposited sediment into all reservoirs (now by echo sounder) it couldn't be realised due to luck of finance.

For this purpose there are stabilised polygonal points around the lakes and defined cross profiles on the reservoir bed. There has been made so-called "0 – situation of the bed" before starting of the reservoir use.

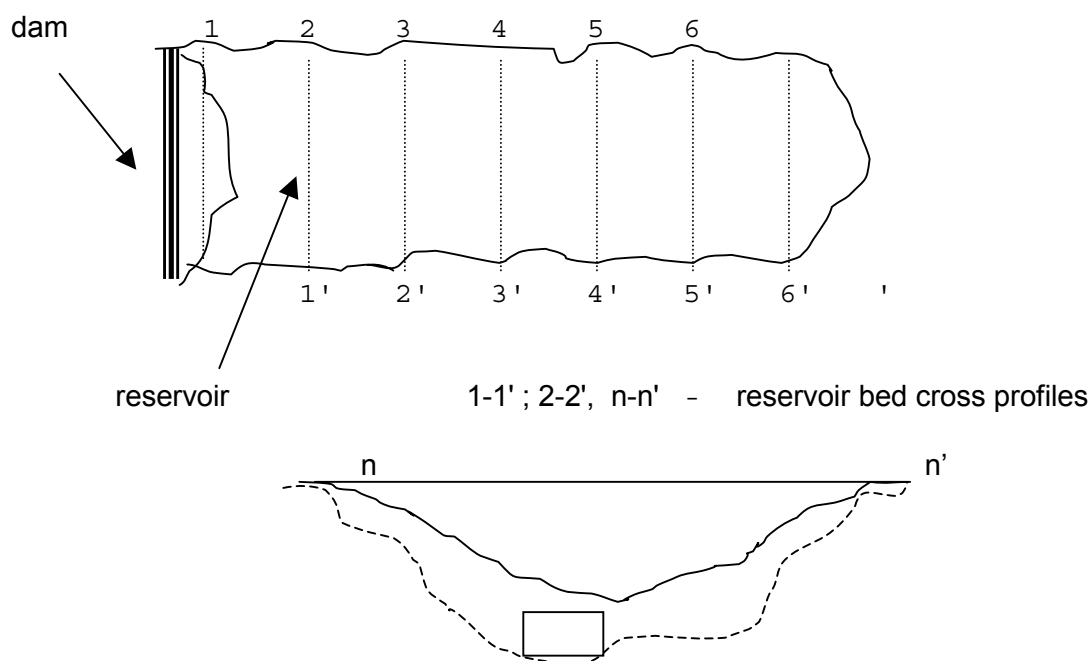


Fig. 2 – Cross profiles stabilisation and measuring for direct measuring by echo sounder

$$V = \sum \frac{F_n + F_{n+1}}{2} * L_{n.(n+1)} \quad (m^3) \quad (1)$$

V – volume of deposited sediment into rathe reservoir (m³)

F – cross profiles area (m²)

L – distances between profiles (m)

Gavrilovic establish 2 difference terms:

- produced eroded material on the catchment area
- transported sediment to the reservoir .

As a result of erosion processes on the catchment area, a lot of erosive material was produced, but only part of this material entire into the reservoir and a part of this material stay somewhere on the catchment area.

$$E = T H_{sr} \pi Z^{1.5} \quad (m^3 / km^2 \cdot year) \quad (2)$$

$$W = T H_{sr} \pi Z^{1.5} F \quad (m^3 / year) \quad (3)$$

$$G_{sp} = T H_{sr} \pi Z^{1.5} Rn \quad (m^3 / km^2 \cdot year) \quad (4)$$

$$G = T H_{sr} \pi Z^{1.5} F Rn \quad (m^3 / km^2) \quad (5)$$

E – specific mean annual produced erosive material

W – mean annual produced material

G_{sp} – specific mean annual transported sediment

G – mean annual transported sediment

$$T - \text{climate coefficient} \quad T = (t / 10 + 0.1)^{-2} \quad (6)$$

t – mean annual temperature (°C)

H_{god} – mean annual total rainfalls (mm)

Z – erosion coefficient by Gavrilovic (0.01 < Z < 1.50)

$$Rn - \text{retention coefficient} \quad Rn = \frac{\sqrt{S * D}}{0.25 * (L + 10)} \quad (7)$$

S – watershed perimeter; D – mean altitude difference

4. Results

4.1. Results from direct measuring with echo sounder

There is enough data from direct measuring only for two the most important reservoirs: Kalimanci (4) and Tikves (11). Here it will be presented results from. From 1968 when these measuring started up to 1991 there were 9 measuring each reservoir. In the year 1991 (year of independence from Yugoslavia) started transitional period. This is a period with war in the neighbourhood and home, period of poorness, low economical standard, so it reflects to water economy enterprise too. In this period there were only few uncompleted measuring spread all over Macedonia, but results are not used for analyses.

Table 2 – Deposited sediments into the 2 most important reservoirs in RM

Reservoir	Total sediment (m ³)	In live storage (%)	In dead storage (%)	Mean annual (m ³ /y)	% of whole reservoir
Kalimanci	9 413 580	72.5	27.5	490 629	7.40
Tikves	29 320 019	54.6	45.4	1 274 783	6.17

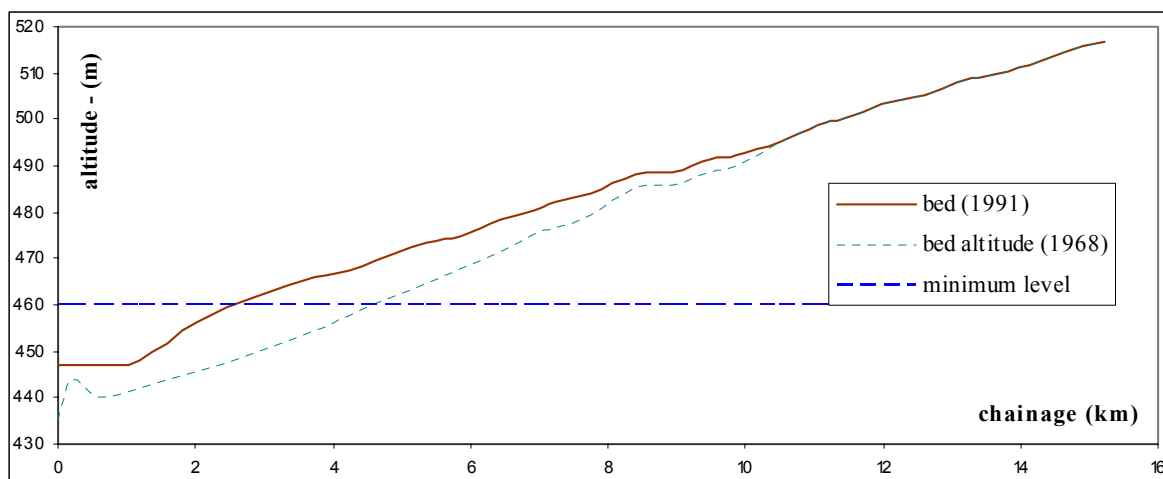


Fig.3 – Sedimentation into the reservoir "Kalimanci" – long profile

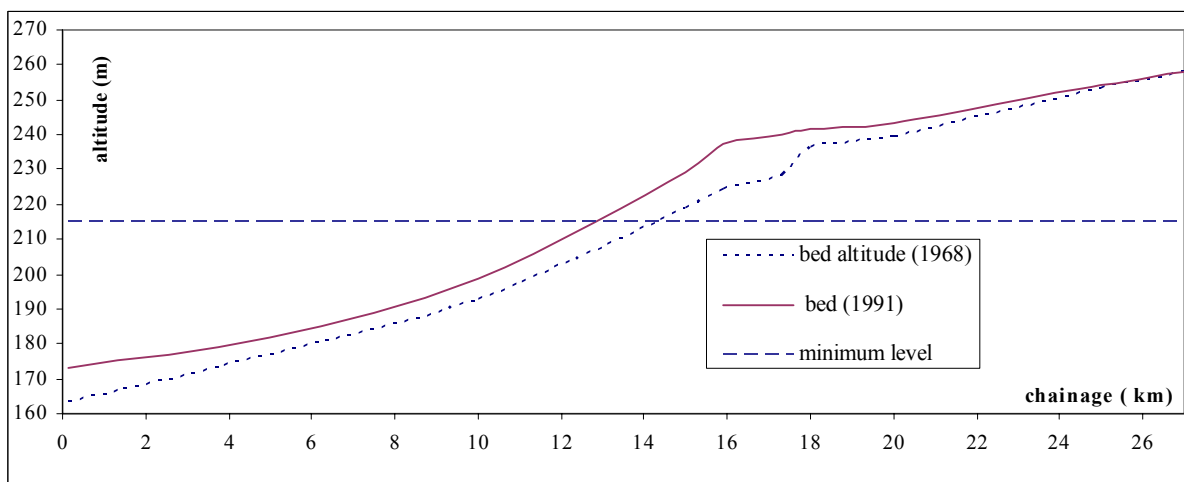


Fig.4 – Sedimentation into the reservoir "Tikves" – long profile

4.2. Results from the estimation by Gavrilovic methodology

Table 3 – Erosion and sediments (by Gavrilovic methodology)

Nr.	Reservoir	F km^2	Z	E $m^3/year$	W $m^3/km^2.y$	G $m^3/year$	Gsp $m^3/km^2.y$
1	Glaznja	99.9	0.71	50911	509	36141	362
4	Kalimanci	1135.5	0.58	1101923	970	418731	368
11	Tikves	5377.6	0.34	2675969	497	1274783	237
14	Turija	213.0	0.27	91578	429	62273	292
15	Vodoca	72.9	0.34	32327	443	16797	230
17	Globocica**	1737.7	0.27	117934	67	102629	59
18	Spilje	2888.8	0.52	807672	279	563154	195
19	Mavrovo	76.8	0.18	16580	215	9119	118

**Catchment area is amputee, so results are not so real

According to the preview realized researches of the erosion potentials at the catchment areas of the reservoirs, the erosion map of RM, elaborates for filling of the reservoirs with erosion deposits and a lot of other projects in the field of erosion, at the above table (Table 3) can be found these data about the quantity of the deposited sediment into few larger and more important artificial reservoirs in RM.

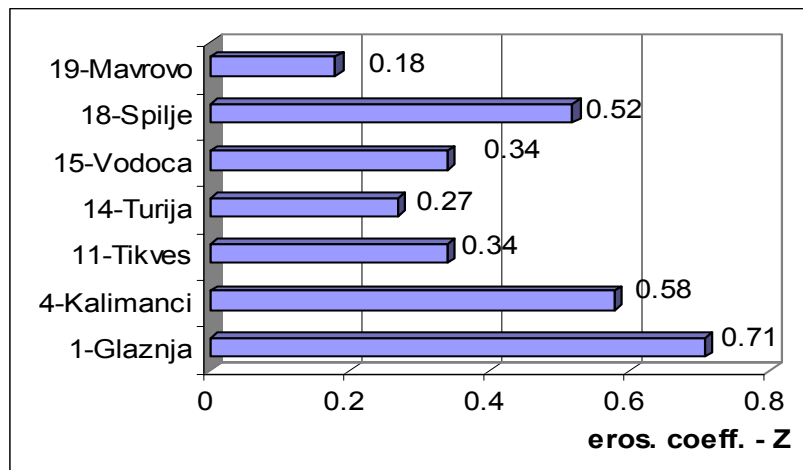


Fig. 5 – Coefficient of erosion – Z - of the catchment area

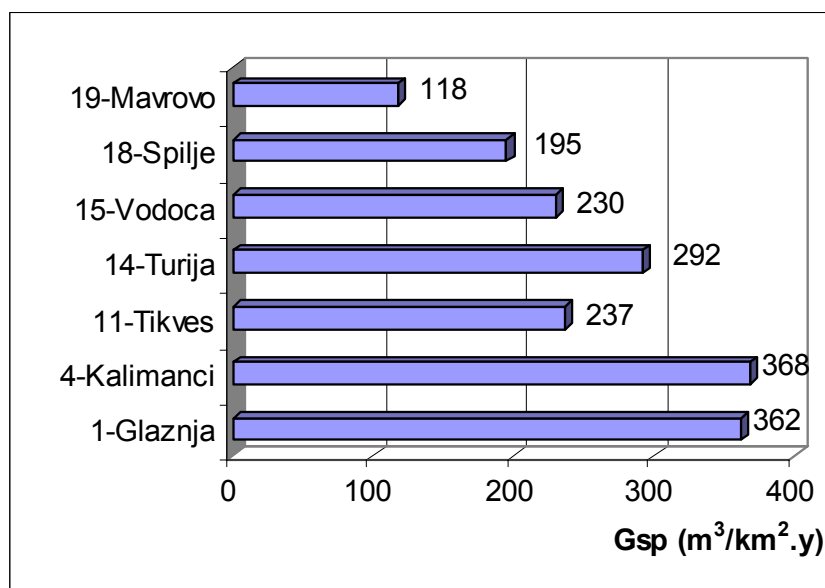


Fig. 6 – Specific mean annual deposited sediment into the reservoirs in RM

5. Discussion and conclusions

As a consequence of the erosion actions at the catchment areas annual intensity of sedimentation into the reservoirs in RM, is more then $3,0 \times 10^6 \text{ m}^3$.

The biggest specific mean annual intensity of sedimentation is into the reservoirs: Tikves – $1.019.341 \text{ m}^3/\text{year}$, Spilje – $563.154 \text{ m}^3/\text{year}$, Kalimanci - $418.731 \text{ m}^3/\text{year}$ act.

If we take in consideration the straight character of the considered part of the catchment area, it is evident that the high of the eroded soil layer of the mountie parts

Very important characteristic for almost all bigger accumulations, especially the accumulations with bigger length of the water level surface is that the bigger part from the layer is deposited at the so called live storage (Fig. 3 and Fig. 4). This is a big problem.

According to the erosion map of R Macedonia, from the total area of the Republic 25.713 km², are undertaken with different intensity of erosion, from 24.813,175 km², or 96,5%, while under accumulation of layer are 899,825 km² or 3,5%. With a biggest degree of percentage of erosion (I-III category of destruction) is undertaken the area of 9.423,62 km² or 36,65% from the territory of R Macedonia.

According to the big importance of the reservoirs for the total development of R Macedonia, with a certain number of them immediately after their construction has started the following of the filling off of the accumulation processes with erosion layers. The main purpose of these measurements is to be determined the dependence between the erosion processes between the catchment area and the filling off of the reservoirs by measurement of the quantities of deposited layer material at the reservoirs, or to be defined the potential of the erosion at the catchment areas. According to the data for specific transfer of the layers (m³/km²/year) and the structure of the erosion processes at the catchment area are predicted some antierosion measurements and some activities for reduction of the middle-year quantities of the produced and transferred layer, and all with the propose to prolonged the profitability of the hidrocyctomas.

With the existing Law for water resources of R Macedonia, the enterprises that are managing with the hydrosystemes, or the reservoirs, besides the other obligations and activities, are obligated to make regular measurements of the deposited layer at the reservoirs and according to that some appropriate measurements were taken in action. The way of following and measurement of the deposed sediment into the reservoirs is regulated with the Rule book for the way of following of the accumulation layers.

All above results show that one of the priorities for future are activities to combating erosion processes in the catchment areas (afforestation of bare lands, torrent control, adequate antierosion agriculture activities, educational projects regulative ...).

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